SPECT Quality Control: A Program Recommended by the American College of Nuclear Physicians and the ACNP Corporate Committee

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Objective: The purpose of this paper is to identify basic quality control procedures and frequency of testing, the results of which yield a "use" or "no-use" condition for a single-head SPECT camera.
Methods: This paper gives a checklist for a variety of quality control tests including detector uniformity, detector resolution and linearity, center of rotation and SPECT resolution and SPECT uniformity.
Results: Four performance tests used in a systematic protocol can be used to determine satisfactory SPECT camera operation. The testing procedures require an average of about 30 min per day.
Conclusions: Specific procedures and testing frequency should meet manufacturer specifications or approval by a qualified physicist.
Key Words: SPECT; quality control

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Establishing that the performance of a SPECT camera is acceptable for clinical use is of utmost importance. Arriving at a decision that the camera meets acceptable performance criteria must be reached efficiently and with high confidence. The American College of Nuclear Physicians and the ACNP Corporate Committee established a working group of physicians, scientists and technologists to develop a SPECT quality control program which meets these goals. Recognizing that the nuclear medicine technologist is most important in obtaining high-quality SPECT images, the procedures in this document are oriented toward understanding, use and interpretation by the technologist.

The ACNP strongly recommends that each SPECT system be thoroughly evaluated before use and annually by a qualified physicist. Once suitable performance of the camera has been established, as few as four performance tests, when used in a systematic protocol, can verify satisfactory SPECT camera operation. These tests include: a) detector uniformity, b) detector resolution and linearity, c) center of rotation and SPECT resolution and d) SPECT uniformity.

SPECT QUALITY CONTROL PROGRAM

Detector Uniformity

A. Testing frequency
   1. Tests should be performed each day the camera is used.
B. Source type
   1. Cobalt-57 sheet source or a *uniformly filled* flood tank may be used for *extrinsic* uniformity testing *or*
   2. A point source located a distance of 6–7 times the maximum detector dimension (or at a distance specified by the manufacturer) for *intrinsic* uniformity testing.
   3. The count rate produced by either source configuration should be about 30k cps or as recommended by the manufacturer.
C. Acquisition parameters
   1. Mount the collimator to be used for ^{99m}Tc SPECT imaging and verify correct analyzer setting for the radionuclide.
   2. Acquire uniformity test image with 64 × 64 matrix for 12 million counts or as recommended by the manufacturer.
D. Uniformity analysis
   1. Visually inspect for and note the presence of nonuniformity in the image.
   2. Process the image with uniformity analysis software supplied by equipment manufacturer.
   3. Evaluate uniformity parameters for any change from established acceptable levels of performance. Most system manufacturers currently provide uniformity analysis for:

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a. integral and differential uniformity for the useful and central field of view (UFOV and CFOV);
b. location of any nonuniformity noted by the software (Note: poor image uniformity and inadequately corrected nonuniformity cause ring, bull's-eye and crescent-shaped artifacts in SPECT transaxial images.)

4. If available, use manufacturer-supplied software to review the following additional information:
   a. image displaying location of pixels with 1, 2 and 3 s.d. differences;
   b. table listing numbers of pixels greater than 1, 2, and 3 s.d.
   c. review the graph that is updated with each uniformity analysis for a trend which may indicate deterioration of performance or significant fluctuation.
5. Maintain for 30 days (or as required by regulatory agencies) a record of all results.
6. Maintain permanently a record of all results which identify problems with the system.

Detector Resolution and Linearity

A. Testing frequency
   1. Performed every other week (alternating with the SPECT uniformity test) or when image quality is in question.

B. Test pattern and source type
   1. Use an orthogonal hole phantom (such as the BRH), parallel-line equal space pattern (PLES) or a four-quadrant test pattern which is designed to be compatible with the manufacturer's software for analysis of linearity and resolution.
   2. Depending on the type of test pattern and software supplied, the pattern may be imaged intrinsically or extrinsically.
   3. A ^{57}Co sheet source or *uniformly filled* flood tank should be used for extrinsic testing and only with a low-energy collimator *or*
   4. A point source located 6–7 times the maximum detector diameter from detector (or as recommended by the manufacturer) should be used for intrinsic testing.
   5. The count rate produced by either configuration should be about 30k cps or as recommended by the manufacturer.

C. Acquisition parameters
   1. Verify the correct analyzer setting for the radionuclide.
   2. Acquire image in 512 × 512 matrix (or as large as possible up to 512) for 5 million counts or as recommended by the manufacturer for the particular phantom.
   3. On successive acquisitions, rotate the pattern to determine response in other quadrants or axes.

D. Resolution and linearity analysis
   1. Visually inspect and note the smallest visible structure in the phantom image.
   2. Visually inspect for linear response of the detector and note any nonlinearity in the images.
      a. The linear structure of the phantom or lines connecting the images of adjacent holes in the phantom should be perfectly straight in both the x- and y-axes.
      b. Compare a current phantom image with an initial image when the camera was known to be working satisfactorily.
   3. If available, use manufacturer-supplied software to evaluate the resolution and linearity parameters for change from your established acceptable levels of performance:
      a. absolute and differential linearity;
      b. the location(s) of significant nonlinearity as noted by the software;
      c. resolution of the detector (FWHM or FWTM) in both the x- and y-axes; and
      d. review the graphs that are updated with each linearity and resolution result which may indicate deterioration of performance or significant fluctuation. (Note: Nonlinearity and planar resolution loss results in loss of resolution in SPECT images)
   4. Maintain a record of all results for 30 days (or as required by regulatory agencies).
   5. Maintain a permanent record of all results which identify problems with the system.

SPECT RESOLUTION AND CENTER OF ROTATION

A. Testing frequency
   1. Test biweekly for systems demonstrated to have stable results.
   2. Test as frequently as with each change of collimator if the system is subject to change of COR with varying detector weight *or*
   3. As recommended by the physicist or equipment manufacturer.
   4. Test whenever image quality is in question.

B. Phantom and sources
   1. Use NEMA Three-Source Phantom (Fig. 1), or a single point source if processing software for the NEMA three source phantom is not available.
   2. Use ^{99m}Tc or ^{57}Co (approximately 50–700 μCi each).
   3. Point source diameter should not exceed 2 mm.

C. Acquisition parameters
   1. Mount the collimator used for SPECT imaging and verify correct analyzer setting for the radionuclide.
   2. Source placement:
      a. place the NEMA phantom level centrally within the field of view of the detector *and/or*
      b. if only a single source is available, position the gantry at 0° or 180° and place the point source about halfway between the center and the edge of the field of view.

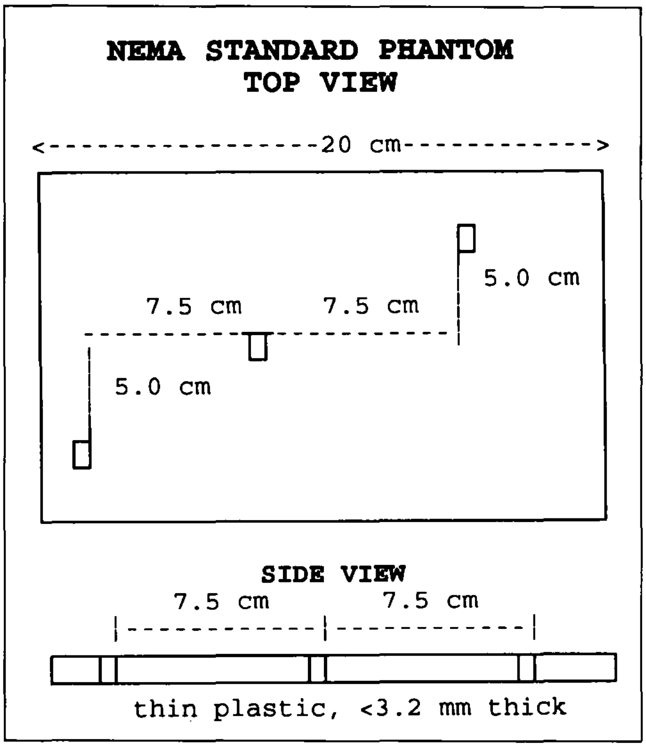

FIGURE 1. The relative positions of the three planar point sources in the NEMA standard phantom. (NOTE: (a) source disks should be securely mounted to the plate with tape; (b) source holders (if ^{99m}Tc droplet is to be used for the point sources) must be securely mounted to the holder plate and (c) align the phantom level and centrally within the field of view.)

   c. Assure that the source(s) remains within the field of view through the complete rotation of the detector.
3. Use a practical radius of rotation (typically 15–25 cm), but always use the same distance when the procedure is repeated.
4. Use a pixel size of 3.5 mm (or less) and use approximately 128 stops.
5. Acquire 7–15k counts at each stop (Note: avoid pixel overflow).

D. Analysis of COR, pixel size calculation and SPECT resolution is possible depending on the phantom, source type and available software.
   1. Calculate COR results and associated data.
      a. Plot x-axis point-source-center versus detector angle and compare the curve to an expected sine curve and
      b. plot y-axis point-source-center versus detector angle and compare to an expected straight line.
   2. For the NEMA phantom, use the Pixel Size program to determine x and y planar pixel dimensions (Note: the 0 or 180° image of the SPECT acquisition may be used for this determination).
   3. Use SPECT reconstruction software (with Ramp filter, cutoff of 1 Nyquist) to obtain images for analysis of SPECT resolution (Note: if there are too many counts in the images for accurate reconstruction, use image manipulation to multiply the images by a fraction <1).
      a. Draw a line profile, using a width up to the FWHM, through the hot spot in the transaxial and sagittal slice containing highest counts (Note: always use the same profile width for future tests).
      b. Plot the resulting profiles and note if the curve has a flat top or a dip at the top, there may be too many counts in the initial images or there may be an uncorrected COR error.
      c. Fit the curve with a Gaussian function and calculate the FWHM in mm for both the x- and y-axes from the transaxial slice and for the z-axis from the sagittal slice.
      d. Calculate SPECT pixel size in the x-, y- and z-axes for the NEMA phantom. (Note: the SPECT x- and y-axes are obtained directly from the transaxial slice and the z-axis pixel size is obtained from the sagittal slice.)
   4. Evaluate the COR, pixel size (planar and SPECT) and SPECT resolution for change from your established acceptable levels of performance.
      a. Evaluate COR graphs for deviation from the predicted sine wave and straight line graphs. (Note: Deviations in the COR graphs may indicate detector or mechanical errors which result in loss of image resolution if not corrected).
      b. Evaluate pixel size for deviation from the initially determined values. (Note: Variance in pixel size can adversely affect detector performance, accuracy of attenuation correction and SPECT reconstruction).
      c. Evaluate resolution of the SPECT reconstruction images in all three axes. (Note: Broadening of the FWHM values may indicate detector resolution deterioration or COR error which results in loss of diagnostic quality).
      d. Review the updated graph documenting any change in COR, pixel size and SPECT resolution.
   5. Maintain a record of all results for 30 days (or as required by regulatory agencies).
   6. Maintain a permanent record of all results which identify problems with the system.

SPECT Uniformity

A. Testing frequency
   1. Conduct tests biweekly or as recommended by the equipment manufacturer.

B. Source type
   1. A cylinder phantom approximately 20 cm in diameter and 20 cm in length is satisfactory. A 1-gal household bleach bottle (15 × 20 cm) is suitable and inexpensive. Head or torso SPECT phantoms with the inserts removed are also acceptable.
   2. Use sufficient ^{99m}Tc to obtain 30k cps (or as recommended by the equipment manufacturer).

3. Assure that the radionuclide is uniformly mixed; some air space in the phantom is recommended to decrease mixing time and radiation exposure during mixing.

C. Acquisition parameters
   1. Mount the collimator used for ^{99m}Tc SPECT imaging and verify correct analyzer setting for the radionuclide.
   2. Place the phantom such that it is in the center of the FOV for detector angles of both 0 and 90°, making certain that the phantom remains level and parallel with the axis of rotation.
   3. Use SPECT acquisition of 128 × 128 matrix for approximately 128 stops (360°) and 200k counts per stop (Note: Use 64 × 64 matrix if correction flood is limited to 30 million counts).

D. Reconstruction
   1. Use a reconstruction filter that would be used for SPECT liver imaging and set the slice thickness to that ordinarily used clinically.
   2. Uniformity correction should be applied if the detector does not apply this correction during acquisition.
   3. Apply attenuation correction using an attenuation coefficient recommended by the equipment manufacturer (generally $0.12/cm^{-1}$ for ^{99m}Tc) and current value for pixel size.

E. Image analysis and visual inspection
   1. Draw a profile that is 5 or 6 pixels thick centered on the object in both the vertical and horizontal directions.
   2. Generate a graph showing counts versus channel.
      a. Expect a flat line after attenuation correction if the proper attenuation coefficient and pixel size are used.
      b. A general concave shape (bowed downward) is due to undercorrection for attenuation (attenuation correction too small).
      c. A general convex shape (bowed upward) is due to overcorrection for attenuation.
      d. The profile may be straight but tilted if the attenuation correction boundary is closer to the edge of the object in one place than another.
   3. Note the presence of rings, bull's-eye or crescent-shaped defects in the images which may be due to inadequate uniformity correction.

DISCUSSION AND CONCLUSIONS

Due to variation in SPECT cameras and computer software, the exact type and frequency of the testing procedures cannot be specified in this report. Specific procedures and testing frequency should be approved by each equipment manufacturer or by a qualified physicist.

TABLE 1
SPECT QC Schedule and Time Requirements

	Frequency	Minutes
Uniformity analysis	Daily	25
Detector resolution and linearity	Biweekly	8
SPECT resolution and COR	Biweekly	23
SPECT uniformity	Biweekly	30

Not all manufacturers have implemented software for all aspects of this recommended SPECT QC program. Additional software is to be made available by equipment manufacturers in the near future which will specify the parameters for data acquisition and analysis. In the interim, the ACNP and the Corporate Committee recommend that acceptable equipment performance values for these procedures be established locally by the users in cooperation with the specific manufacturer and/or a qualified physicist.

The testing frequency and typical time requirements for each test are listed in Table 1. The specific times required for each type of SPECT camera vary due to collimator changing and time required to run the software applications. To facilitate scheduling, the biweekly testing can be alternated to reduce the amount of QC work scheduled on any one day. Providing safety and security of radioactive sources can be assured; some testing can be set up in the evening with analysis the following morning.

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SUGGESTED READING

1. King MA, Zimmerman RE, Links JM. *Imaging hardware and software for nuclear medicine.* American Association of Physicists in Medicine Symposium Proceedings No. 6. New York: American Institute of Physics; 1988.
2. Croft BY. *Single-photon emission computed tomography.* Chicago, IL: Year Book Medical Publishers; 1986.
3. English RJ, Brown SE. *Spect single-photon emission computed tomography.* New York: Society of Nuclear Medicine; 1990.
4. Performance measurements of scintillation cameras. *NEMA Standards Publication No. NU 1.* Washington, DC: National Electrical Manufacturers Association; 1994.
5. Rotating scintillation camera acceptance testing and quality control. *AAPM Report No. 22.* New York: American Institute of Physics; 1987.
6. Computer-aided scintillation camera acceptance testing. *AAPM Report No. 9.* New York: American Institute of Physics; 1981.
7. Scintillation camera acceptance testing and performance evaluation. *AAPM Report No. 6.* New York: American Institute of Physics; 1981.
8. Sorenson JA, Phelps ME. *Physics in nuclear medicine,* 2nd ed. Orlando, FL: Grune and Stratton; 1987.
9. Murphy PH. Acceptance testing and quality control of gamma cameras including SPECT. *J Nucl Med* 1987;28:1221–1227.
10. Simmons GH. *The scintillation camera.* New York: Society of Nuclear Medicine; 1988.